Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 511740
UNCLASSIFIED	

TITLE

Measurement of Radiation Protection Factors for Contaminated Vehicles

System Number:

Patron Number:

Requester:

Notes:

DSIS Use only:

Deliver to:

DEFENCE DÉFENSE

Measurement of Radiation Protection Factors for Contaminated Vehicles (U)

D.S. Haslip, T. Cousins, J.R. Brisson, B.E. Hoffarth and T.A. Jones
Defence Research Establishment Ottawa

J. Dubeau
Aylmer, Québec

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL MEMORANDUM
DREO TM 1999-070
March 1999

National Defence Défense nationale

Canada

DEFENCE DÉFENSE

Measurement of Radiation Protection Factors for Contaminated Vehicles (U)

D.S. Haslip, T. Cousins, J.R. Brisson, B.E. Hoffarth and T.A. Jones
Radiation Effects Group
Space Systems Technology Section

J. Dubeau
Detec
Aylmer, Québec

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL MEMORANDUM
DREO TM 1999-070
March 1999

Project
6EE12

ABSTRACT

The gamma-ray radiation protection factor for contaminated vehicles has been defined and measured for two locations inside the CF Grizzly. The measurements were performed with a ^{60}Co gamma-ray source at the DREO fallout field simulation facility. In the driver's seat, the protection factor was observed to be 11.9, while in a passenger's position closer to the rear of the vehicle, the protection factor was considerably smaller, at 8.0.

RÉSUMÉ

Le facteur de radioprotection de rayons gamma pour le véhicule souillé a été défini et mesuré à deux positions à l'intérieur du CF Grizzly. Les mesures ont été exécutées avec une source de rayons gamma ^{60}Co au service de simulation de zone de retombées radioactives du CRDO. Dans le siege du conducteur, le facteur de protection a été observé pour être 11.9. À la position du passager, plus près à l'arrière du véhicule, le facteur de protection était considérablement réduit à 8.0.

EXECUTIVE SUMMARY

Gamma-ray protection factors define the degree to which the occupant of a vehicle or structure is protected from radioactive sources outside. It can be defined as the ratio of the dose rate felt by an individual in a contaminated field to that felt by an individual in a similarly contaminated vehicle. They are a useful statistic for the comparison of vehicle designs.

The gamma-ray radiation protection factor for contaminated vehicles has been measured for two locations inside the CF Grizzly. The measurements were performed with a ^{60}Co gamma-ray source at the DREO fallout field simulation facility. The measurements show that, for a uniform vehicular contamination, dose rates are considerably smaller in the driver's seat than they are for a passenger's position closer to the rear of the vehicle.

With this "proof of concept" completed, it is now important to make comparisons between measurements made in this fashion and at the Centre de Decontamination et de Protection in Bourges, France.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

The threat of exposure of Canadian Forces (CF) and NATO personnel to gamma-ray radiation is well-recognised [1]. This radiation may derive from a number of sources, including weapons fallout, sabotaged reactors, and radiological dispersal weapons. In these scenarios, a situation may arise whereby some form of gamma-ray-emitting contamination settles onto a wide area, including any vehicles in this area. The risk of contamination to vehicles also arises when an initially clean vehicle is driven through a radiologically contaminated area, so that radioactive dust can be stirred up and re-settle on the vehicle.

Given this known threat, it is important to know the degree of protection that is afforded to personnel inside CF vehicles, both from radiological contamination on the ground and on the vehicles themselves. In addition, there is an operational requirement for one to be able to estimate the extent of such contamination outside a vehicle from measurements of gamma-ray dose rates made inside the vehicle.

To date, much effort and considerable progress has been made on the measurement and estimation of radiation protection from uniform contamination on the ground (infinite plane) [2]. However, less attention has been paid to the very important issue of vehicular contamination. This report documents the first measurements made at DREO of protection from vehicular contamination, on the CF Grizzly.

2.0 SIMULATION OF CONTAMINATED VEHICLES

2.1 Simulators Within NATO

There are four facilities within NATO at which the radiation protection factors for contaminated vehicles can be measured. They are:

(a) The Centre de Decontamination et de Protection (DEP) at Etablissement Technique de Bourges (ETBS), in France. This site has the capability to contaminate vehicle surfaces with radioactive ^{140}La dust. This permits the measurement of both radiation protection factors and the efficacy of decontamination efforts [3].

(b) The Contamination / Decontamination facility at Wehrwissenschaftliches Institut für Schutztechnologien, in Germany. At this facility, vehicles may be contaminated with a radioactive rain, containing ^{140}La, ^{24}Na, ^{82}Br, or ^{152m}Eu [4].

(c) The blanket of point sources, developed by the Aberdeen Test Center in the USA. Point sources of ^{60}Co are embedded in a blanket (on a 0.5 m grid) and draped over a vehicle.

(d) The DREO Source-in-a-Tube Facility. This newly completed effort uses a motor system to pull an enclosed radioactive source through a tube over the surface of a vehicle. This system allows the measurement of radiation protection factors with considerably less radiation hazard than is present at facilities (a) and (b) described above. It will also be demonstrated that this method permits the identification of local deficiencies in the protective shell of the vehicle.

2.2 Vehicle Protection Factor

A number of definitions have been proposed for the protection factor of a contaminated vehicle. In this report, the protection factor (*PF*) is defined as the ratio of the (unshielded) dose rate received at 1 m above an infinite plane of uniform contamination to that received at a given spot in a vehicle from the same areal contamination on that vehicle. That is,

$$PF = \frac{FFDR(1\,\mathrm{m})}{VDR(\mathrm{pos})} \qquad (1)$$

where $FFDR(1\ \mathrm{m})$ = free-field (unshielded) dose rate @ 1m height for an infinite plane of contamination

$VDR(\mathrm{pos})$ = dose rate at a position "pos" in a vehicle for the same areal contamination on that vehicle

It is worth noting that, because the surface area of a vehicle is small compared to that of a field, it should be expected that the protection factor is larger than unity. The possible exceptions to this are cases in which the position of interest is very close to one of the vehicle's exterior surfaces, so that the contribution to the dose rate from a small section of the vehicle surface becomes overwhelmingly large.

By itself, the protection factor defined above is not a very useful number. It does not explicitly give the dose rate inside a contaminated vehicle. Also, since it is the ratio of dose rates corresponding to two very different situations, the significance of its magnitude is not immediately apparent. However, one can profitably compare the protection factors of two different vehicles, and as such the number is useful.

2.3 DREO Approach to Contamination Simulation

The facilities at Bourges and in Germany provide very realistic simulations of vehicular contamination. However, because their methods use radioactive dust and liquids, licensing considerations would prohibit DREO from constructing a similar facility. Thus, a different approach is desired.

This is achieved through the arrangement depicted in Figure 1. A rubber tube is draped over the vehicle at various positions along the vehicle's length, and held in place by magnets. A radioactive ^{60}Co source, contained in a lightweight holder, is pulled through the tube by a pair of motors (see Figure 2). As the source moves over the vehicle, gamma-ray detectors inside the vehicle measure the dose rate.

Ideally, one would like to smear some radiological agent uniformly over a small section of the vehicle surface and measure the dose rate at key positions inside the vehicle. When those measurements are complete, the agent would be completely removed and a

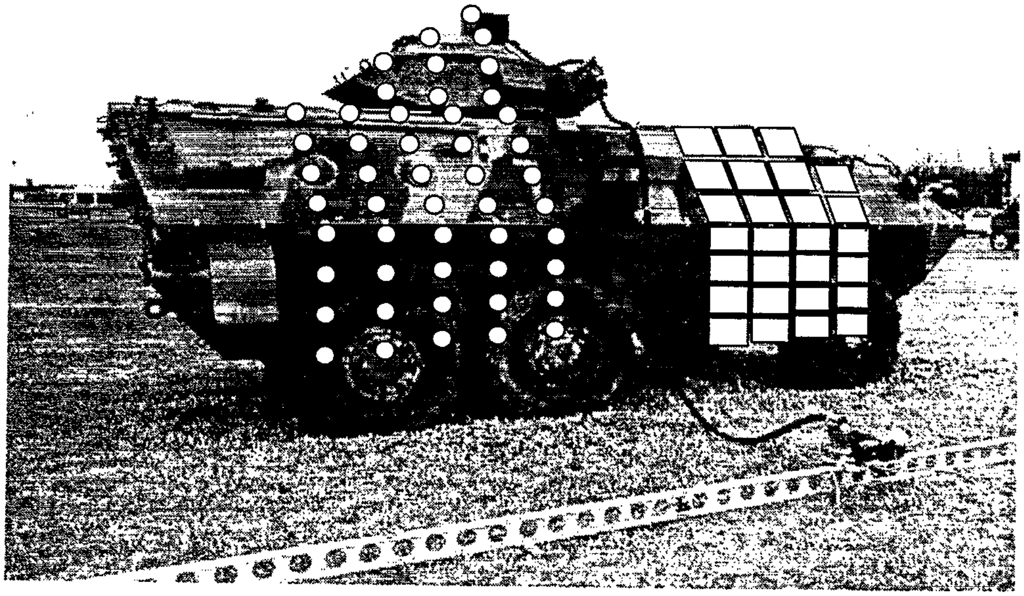

Figure 1: Experimental set-up. A rubber tube was draped over the Grizzly at one foot intervals along the side of the Grizzly. Two motors (one shown at bottom right) pulled the source through the tube and over the vehicle. At the front of the vehicle is shown a schematic division of the Grizzly surface into smaller surfaces. At the rear is shown a series of point sources that could be used to approximate such a tiling.

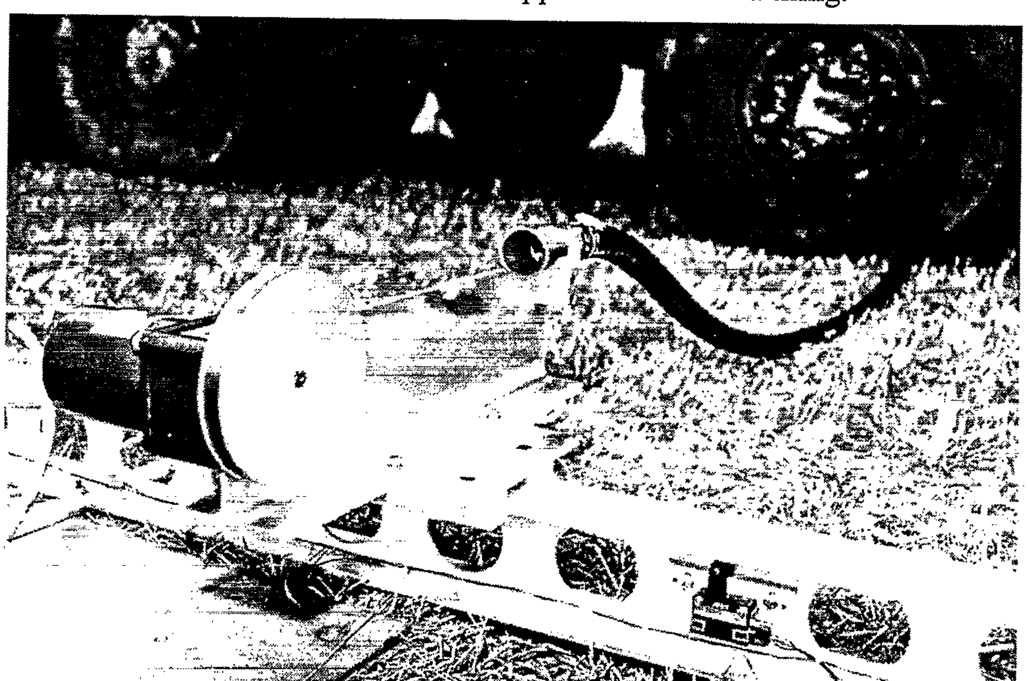

Figure 2: The motor and pulley system. At left is one of the two motors and its gears. This is connected to a pulley. Between the pulley and the opening of the tube is the source holder. The source is pulled through the tube by fine fishing line.

new patch of the vehicle would be contaminated. This would be repeated until all vehicle surfaces had been contaminated. A schematic division of the CF Grizzly's surface into such patches is shown at the front of the vehicle in Figure 1. This method would provide an accurate measurement of the dose rate inside a contaminated vehicle, and provide the analyst with a picture of how the vehicle's shielding varies as a function of where the contamination is located.

In the DREO system, these small patches of contamination are replaced by the slowly moving source. Thus, a detector making frequent measurements will measure the dose due to what is essentially a series of point sources, as depicted schematically at the rear of the vehicle in Figure 1. Of course, the points are actually smeared in the vertical direction by the movement of the source, but this actually improves the approximation to the rectangular surfaces. The horizontal spacing between these points is defined by the tube positions. The vertical spacing is defined by $d=vt$, where v is the velocity of the source and t is the time between measurements. In the measurements described in this report, d is approximately 3.9 cm, with a sampling time t of one second. A second detector used in these trials measures only the dose for a complete trip of the source over the vehicle. This is approximately equal to the dose that would be measured for a uniform strip of contamination.

The series of point sources is an excellent approximation to a collection of contaminated surfaces, and it is limited only by the spacing between the tube positions. That is, if the dose due to contamination varies significantly over the surface being approximated, then the value of a point source approximation is suspect. Thus, in choosing the number of tube positions to measure, one must strike a balance between experimental accuracy and effort. In this report, adjacent tube positions were w=30.5 cm apart.

In the experiment described in this report, the ^{60}Co source had an activity of A=1.41 mCi (A 3.60 mCi source was also used, but the results for this source are scaled down to the 1.41 mCi source). Thus, in one second, the dose measured is equivalent to that from a contaminated region (area dw) with a uniform areal contamination of $A/(dw)$ mCi/cm^2, present for one second at the source position. Similarly, one can equate the dose measured for one trip of the source over the vehicle to the dose for a "strip" of contamination, areal contamination as above, width w, present for one second. Finally, the dose measured over the entire experiment is the same as that expected for a one-second measurement of a uniformly contaminated vehicle, with areal contamination as above.

3.0 EXPERIMENTAL RESULTS

3.1 Vehicle Configuration

The vehicle used for these tests was the CF Grizzly. No supplementary armour was present on this vehicle.

3.2 Detector Positions

Two detectors were used in making these measurements. The DREO BGO detector [5] was placed on one of the passenger benches on the left side of the Grizzly (see Figure 3). It was placed near the chest height of a seated soldier. This detector was turned on when the source began moving up one side of the vehicle, and was turned off when it left the other side. The DREO Airborne Microspec [6] was also set up in the Grizzly, with its 3"×2" NaI(Tl) detector placed on the driver's seat (see Figure 4). The Airborne unit was used because it can be turned on and off remotely. It also has the advantage of providing time-indexed data every second. With this capability, one can see the dose rate as a function of source position over the vehicle.

3.3 Measurement of Protection Factors

Figure 5 – Figure 24 show the dose rate measured by the Airborne Microspec as a function of time, at a number of different tube positions. The abscissa is the position of the source inside the tube. The dashed vertical lines show where the tube reaches the top of the vehicle. These figures clearly illustrate the shielding properties of individual parts of the vehicle. For instance, Figure 6 - Figure 9 have a significant reduction in dose rate at the right side of the figure, indicating the shielding offered by material on that side of the vehicle, particularly the engine block. The dose rate reduction in Figure 15, relative to Figure 14, demonstrates how contamination on the turret is much less important to the driver than contamination just in front of the turret. Figure 17 is a particularly good example of the additional shielding provided by the turret and the equipment inside it. These plots also show variations in the dose rate due to irregularities in the vehicle shielding. This is illustrated best in Figure 15. The origin of the spike in the dose rate at 36 feet is not known, but demonstrates a significant variation in the driver's shielding.

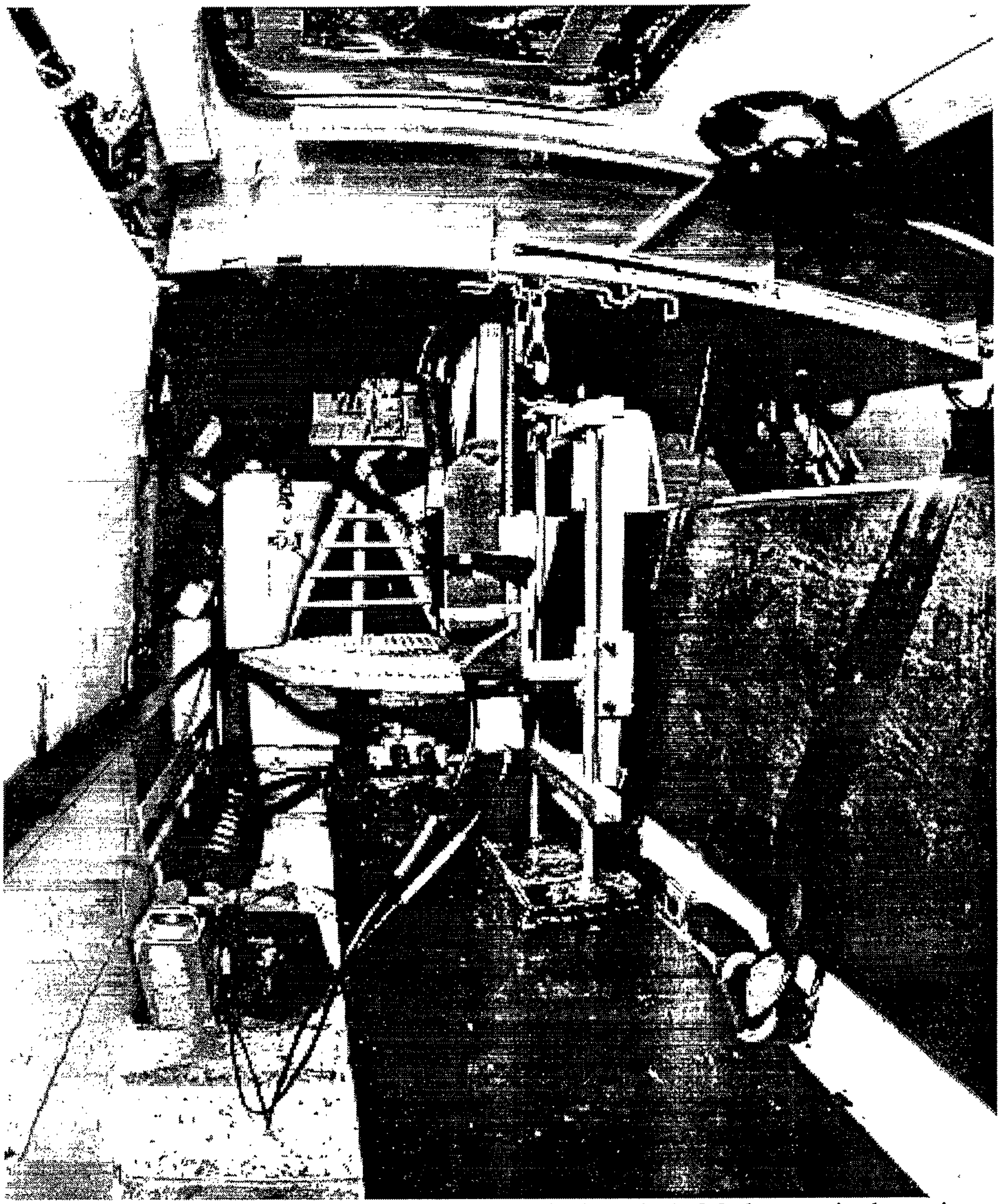

Figure 3: The left side bench at the rear of the Grizzly. The BGO detector is shown just to the left of the centre of the picture, at what would be chest height for a seated soldier. This is approximately fourteen to fifteen feet from the front of the vehicle.

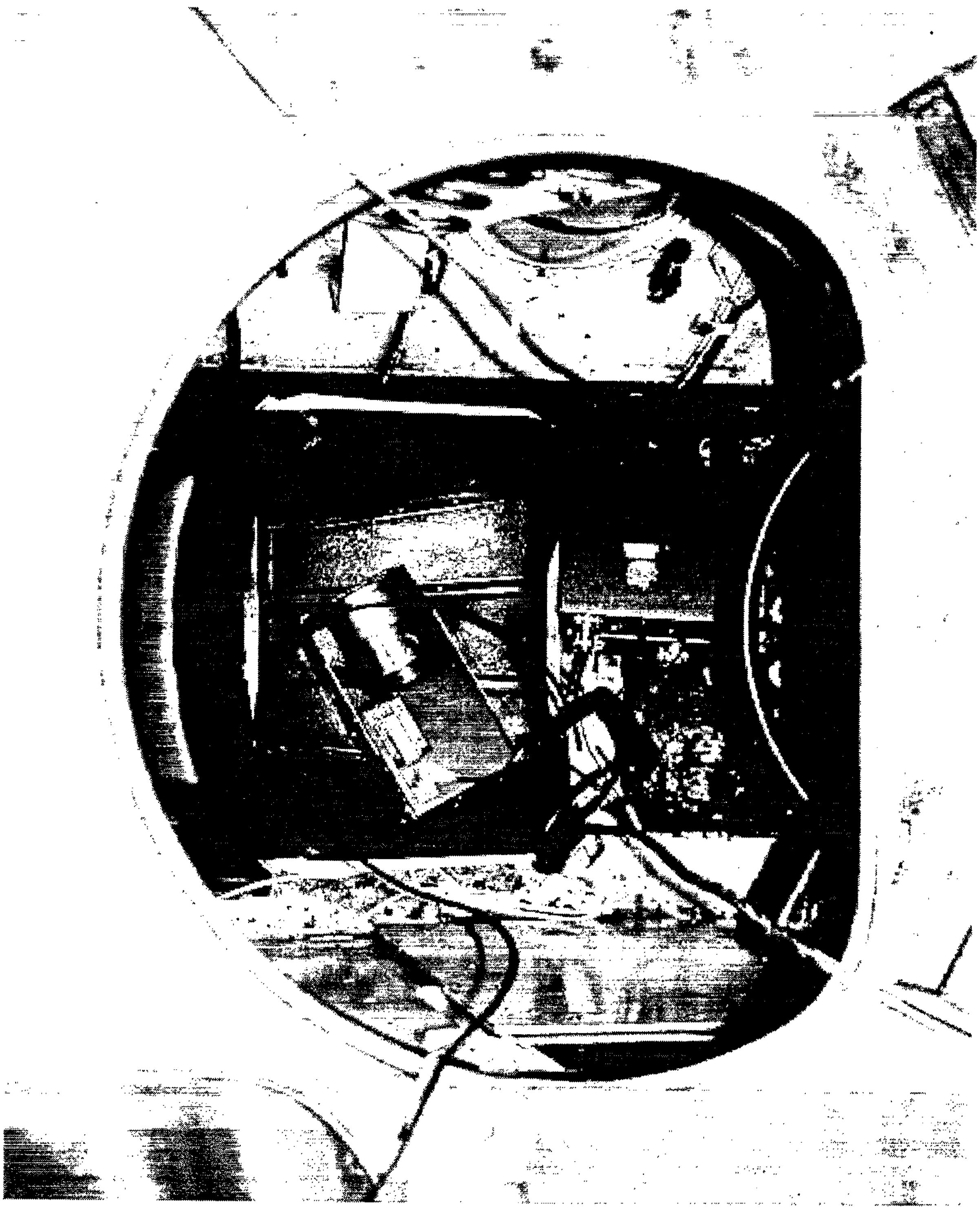

Figure 4: The driver's seat of the Grizzly, viewed from above through the hatch. Sitting on the seat is the NaI(Tl) detector used in these experiments. This seat is approximately six feet from the front of the vehicle.

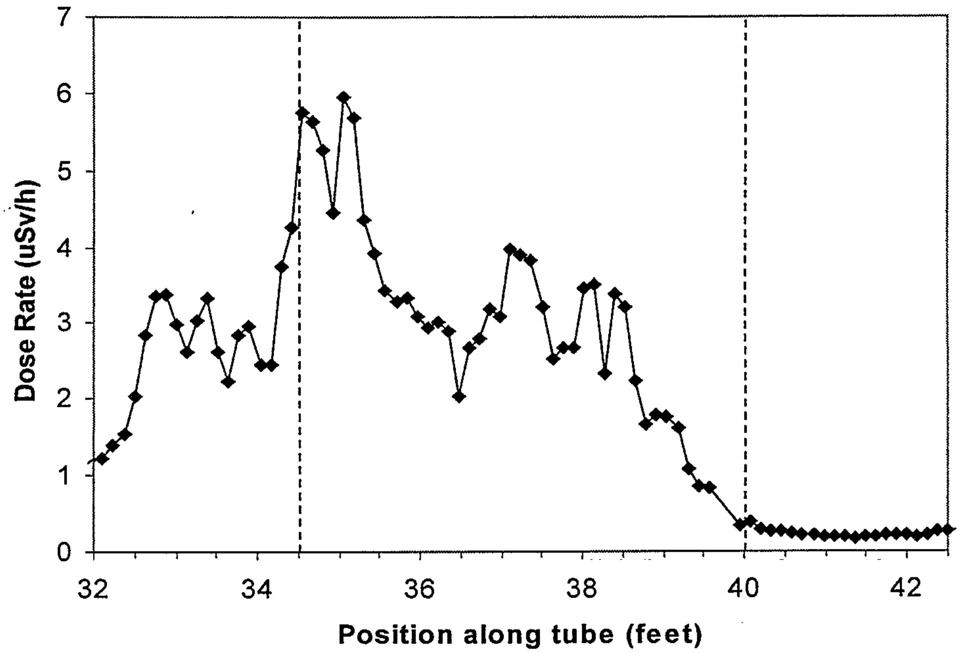

Figure 5: Dose rate as a function of source position, with the tube running along the front edge of the Grizzly. The driver's side of the vehicle is at the left of the figure.

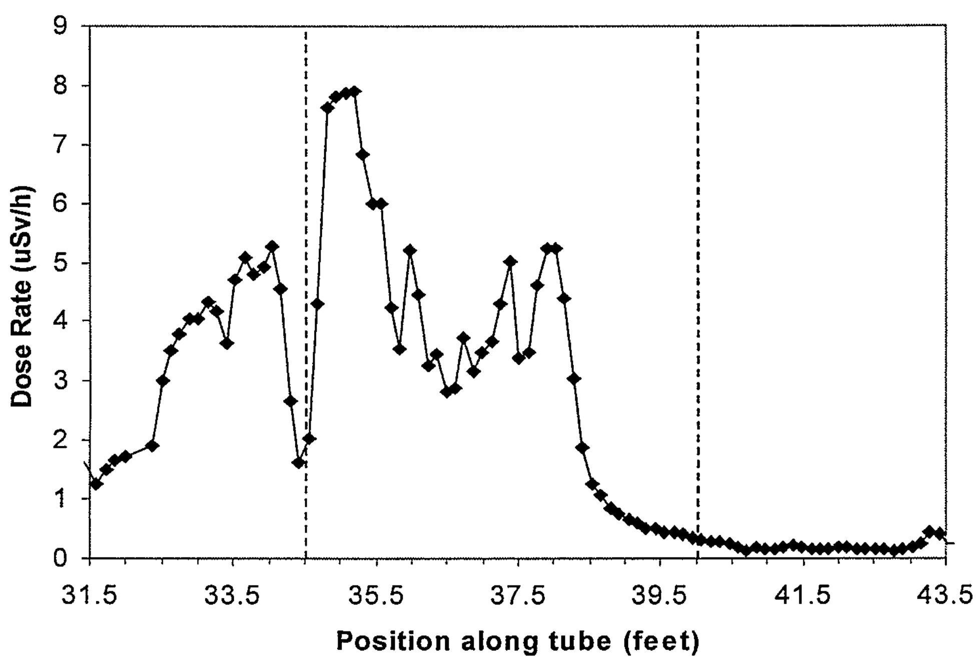

Figure 6: Same as the previous figure, but for a tube position one foot from the front of the vehicle. The shielding due to the engine (right side of figure) is apparent.

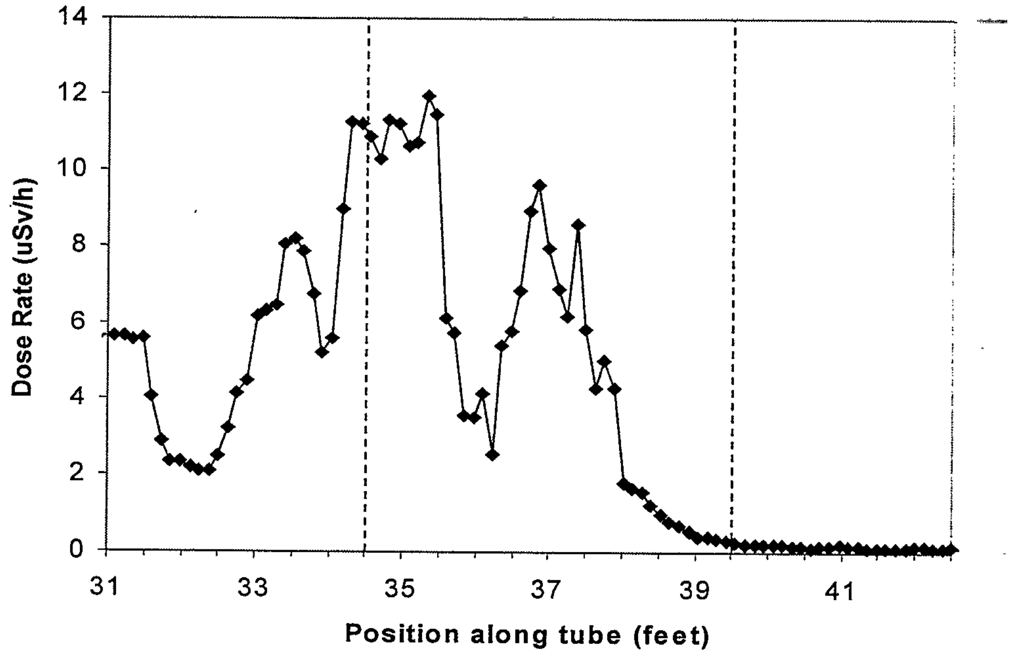

Figure 7: Dose rate versus source position, with the tube two feet from the front of the Grizzly.

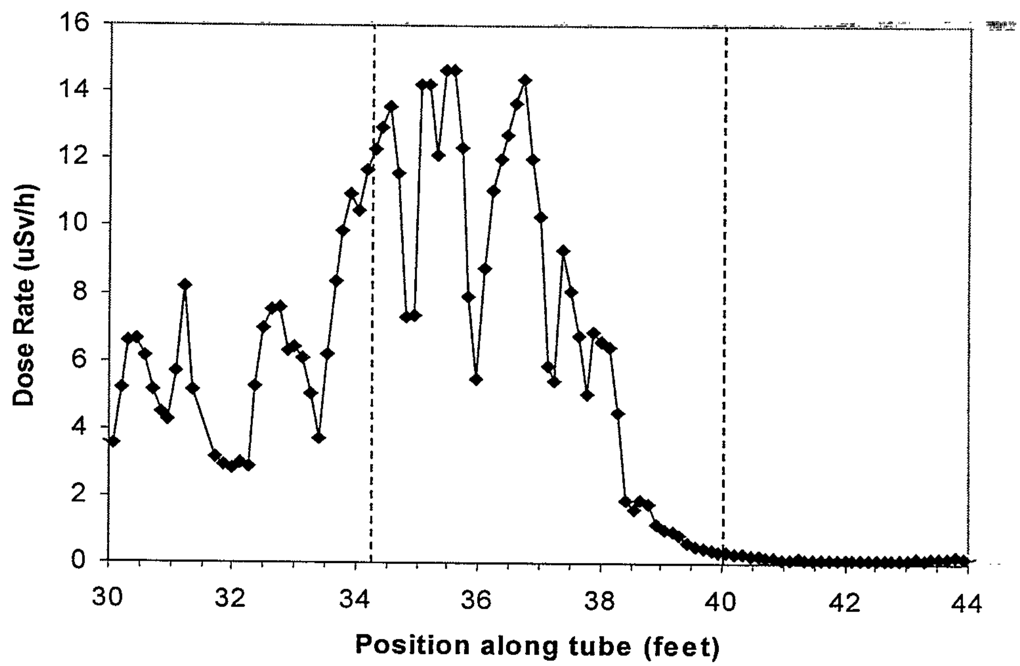

Figure 8: Dose rate versus source position with the tube three feet from the front of the vehicle.

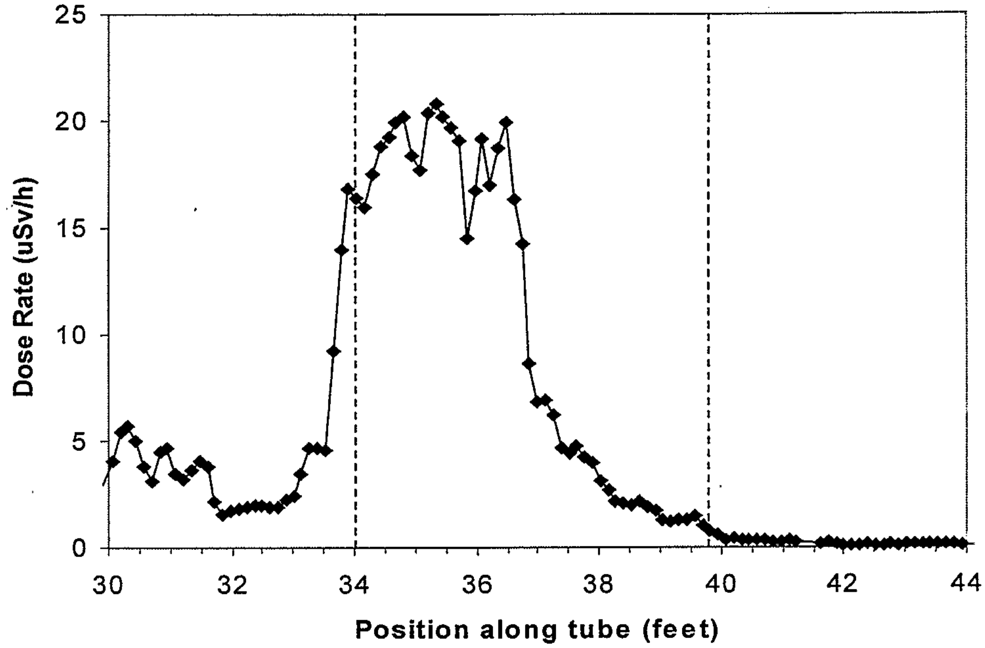

Figure 9: Dose rate versus source position when the tube is four feet from the front of the vehicle.

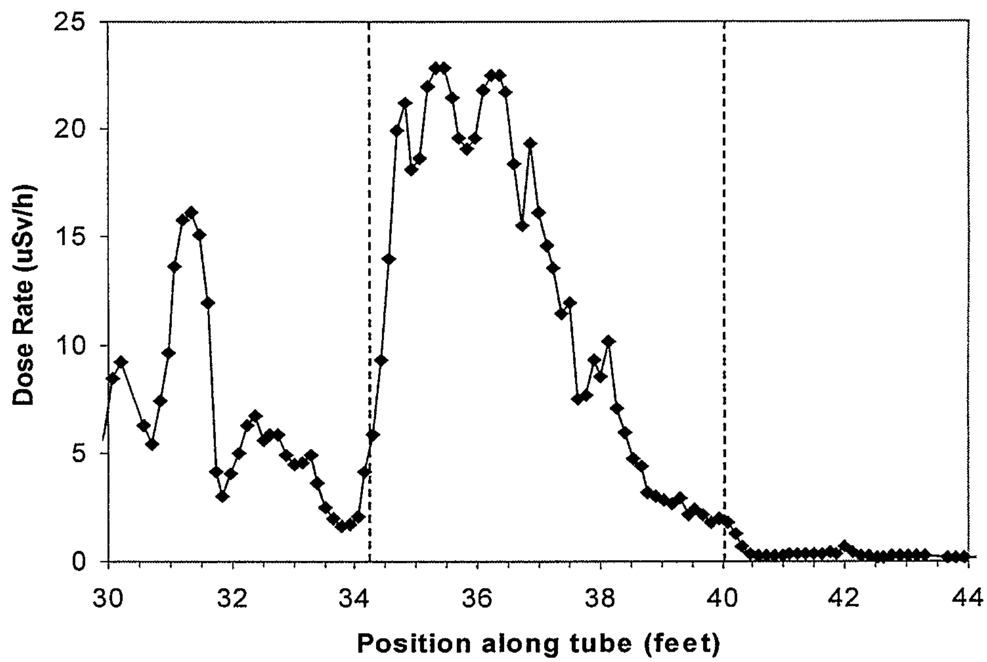

Figure 10: Dose rate versus source position with the tube five feet from the front of the vehicle. The highest dose rates are seen with the tube in this position.

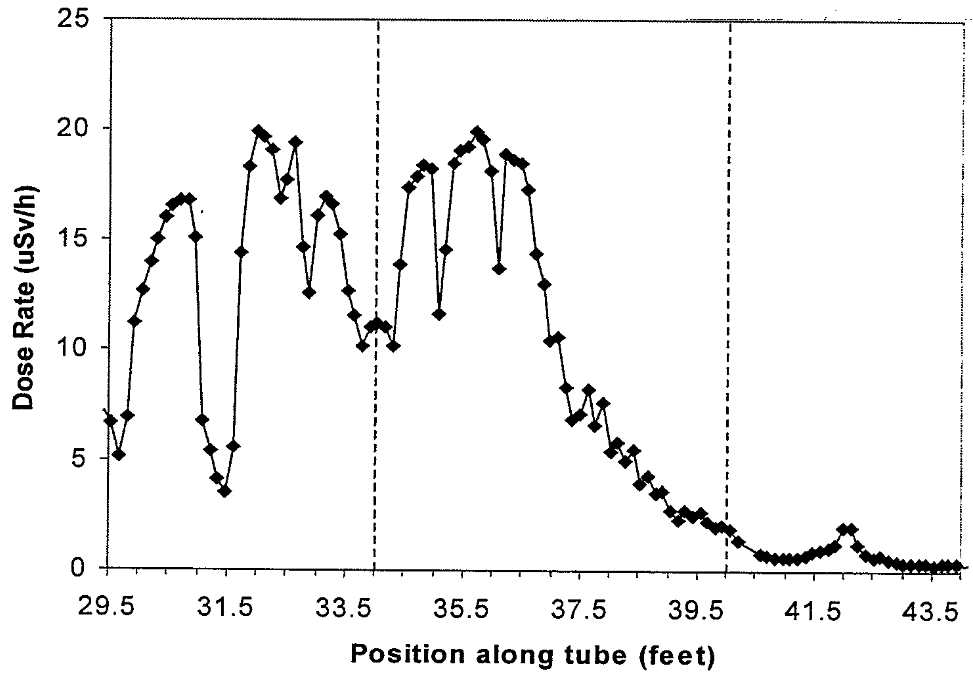

Figure 11: Dose rate versus source position, with the tube six feet from the front of the vehicle.

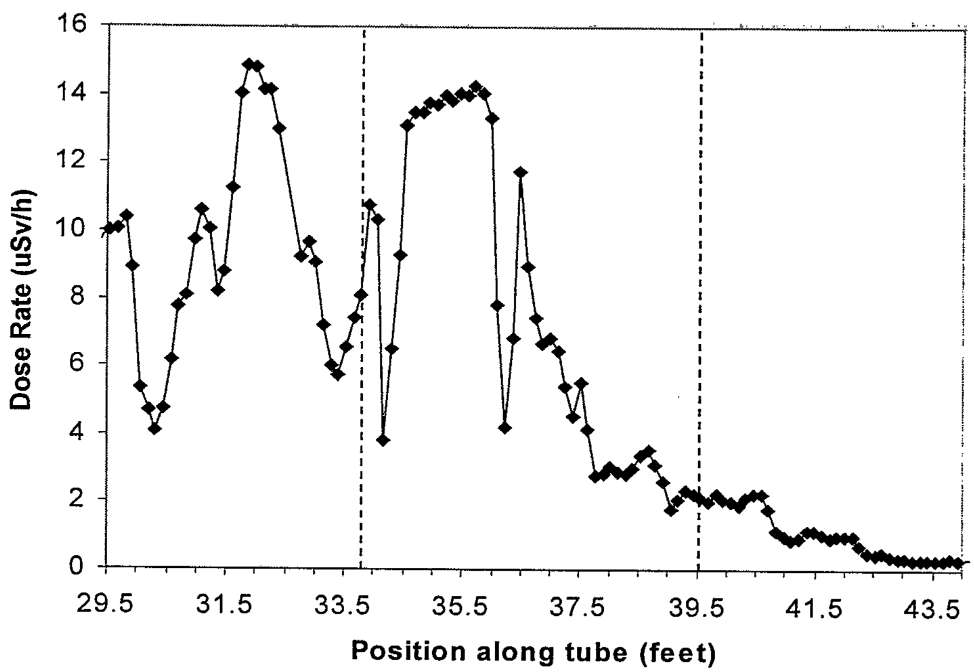

Figure 12: Dose rate versus source position with the tube seven feet from the front of the vehicle.

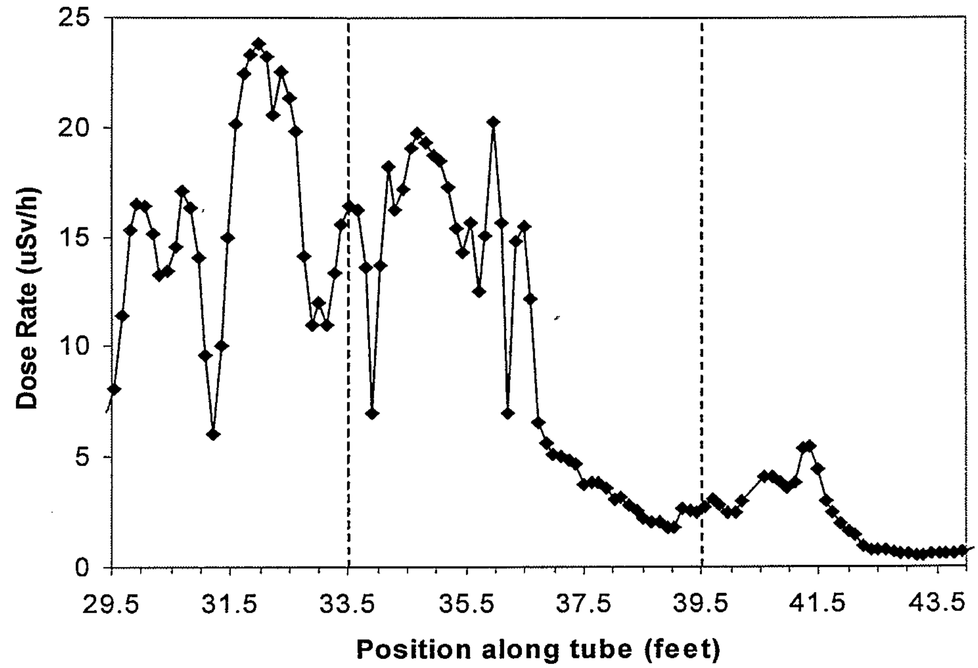

Figure 13: Dose rate versus source position, with the tube eight feet from the front of the Grizzly. In this and subsequent plots, a 3.4 mCi source was used.

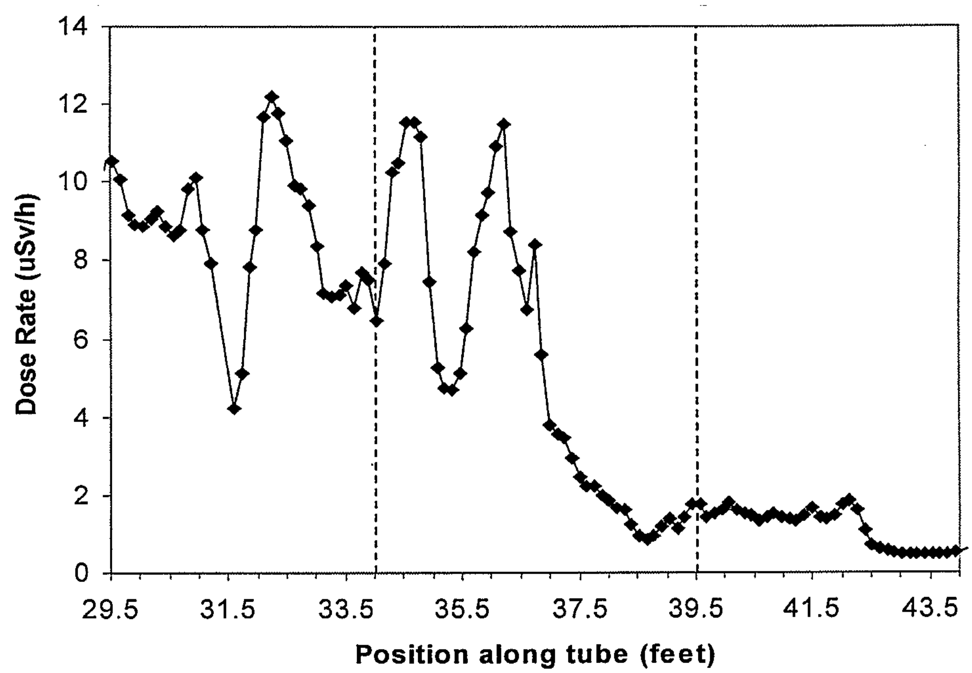

Figure 14: Dose rate versus source position with the tube nine feet from the front of the vehicle. This puts the tube right in front of the turret.

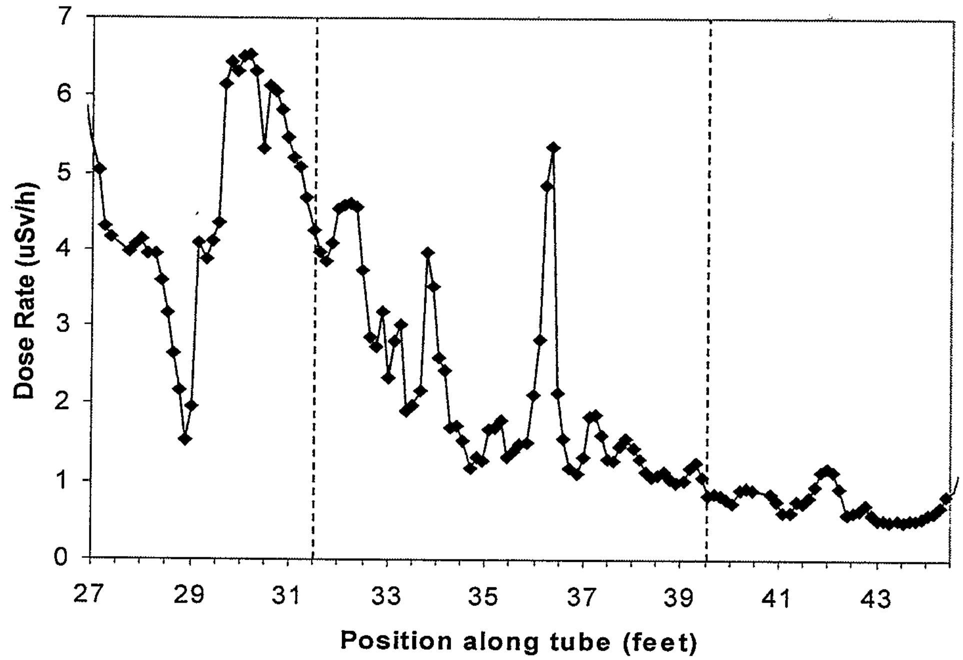

Figure 15: Dose rate versus source position, with the tube ten feet from the front of the vehicle, on top of the turret. The striking difference between this plot and Figure 14 evidences the significant shielding provided to the driver by the turret.

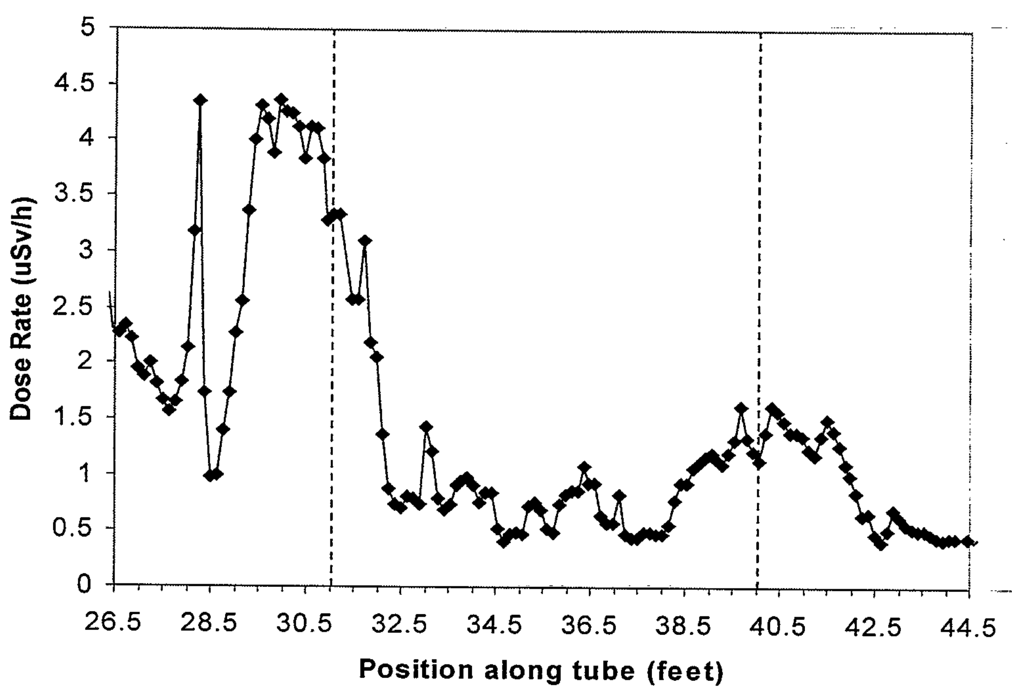

Figure 16: Dose rate versus source position with the tube eleven feet from the front of the vehicle.

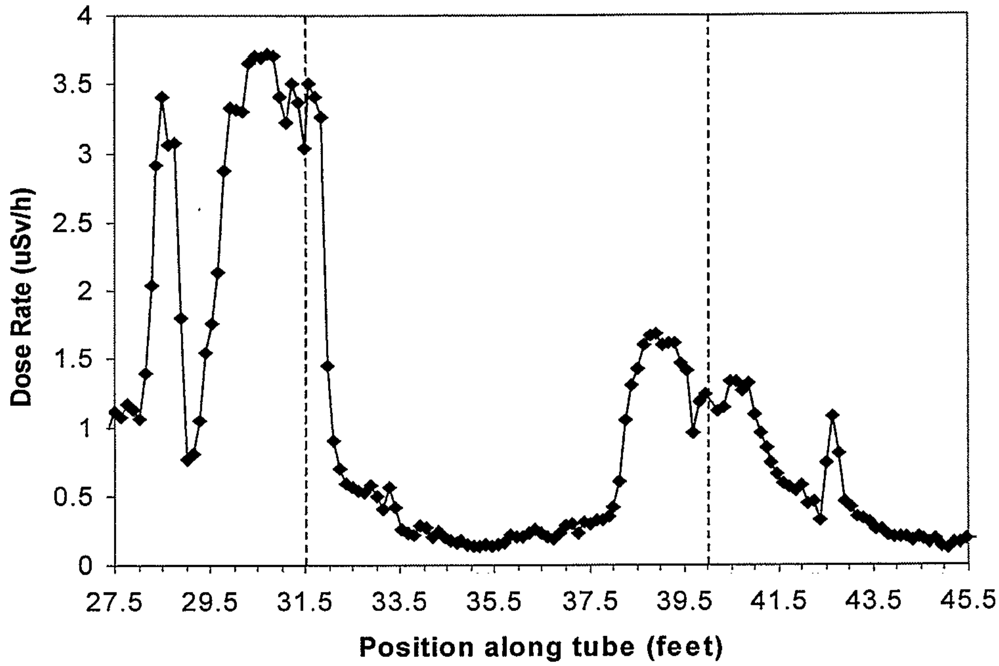

Figure 17: Dose rate versus source position, with the tube twelve feet from the front of the vehicle. The shielding due to the turret is clear.

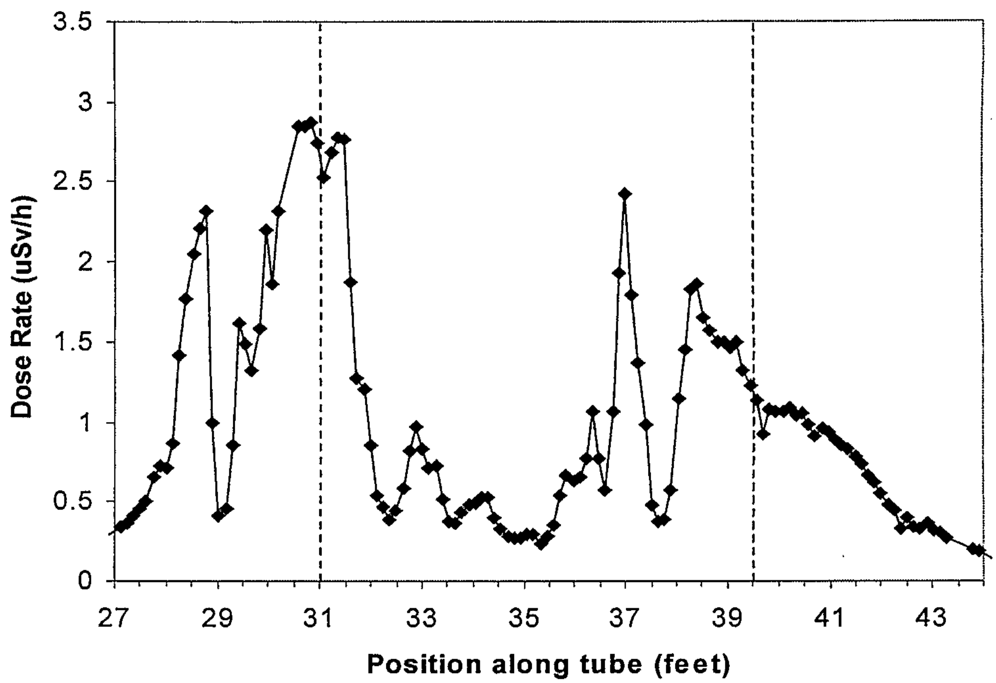

Figure 18: Dose rate versus source position with the tube thirteen feet from the front of the Grizzly.

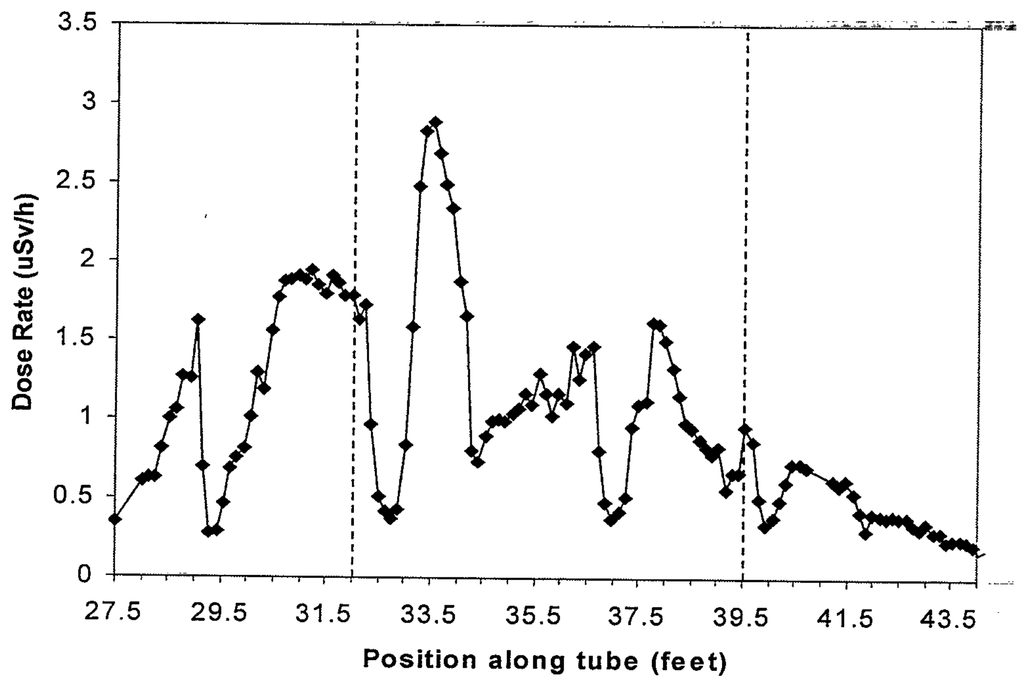

Figure 19: Dose rate versus source position, with the tube at the rear end of the turret.

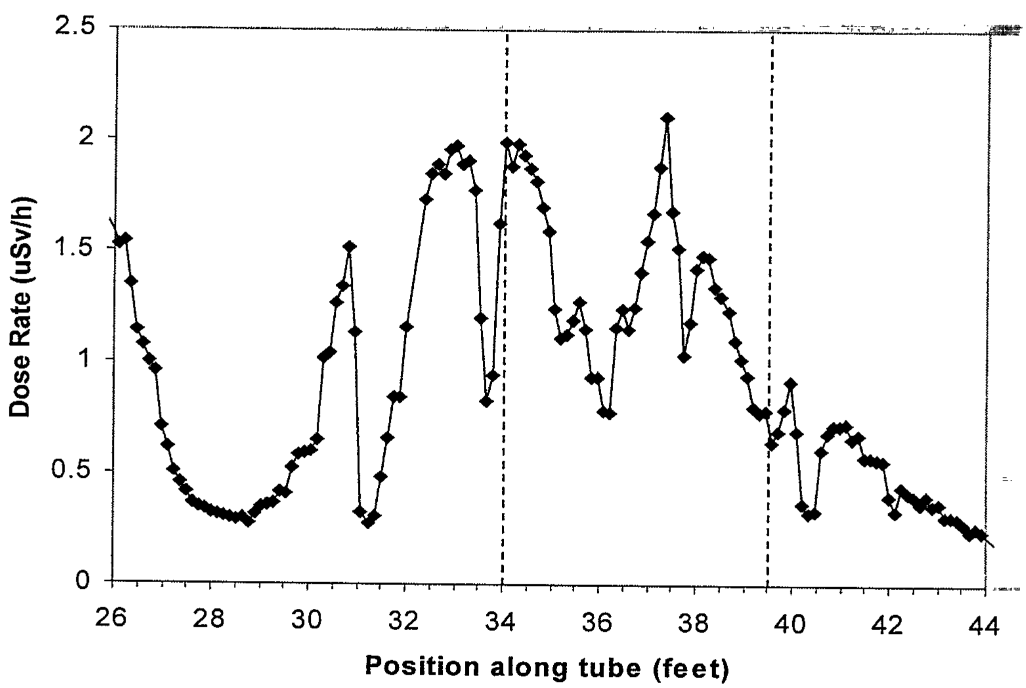

Figure 20: Dose rate versus source position with the tube below the overhang at the rear of the turret.

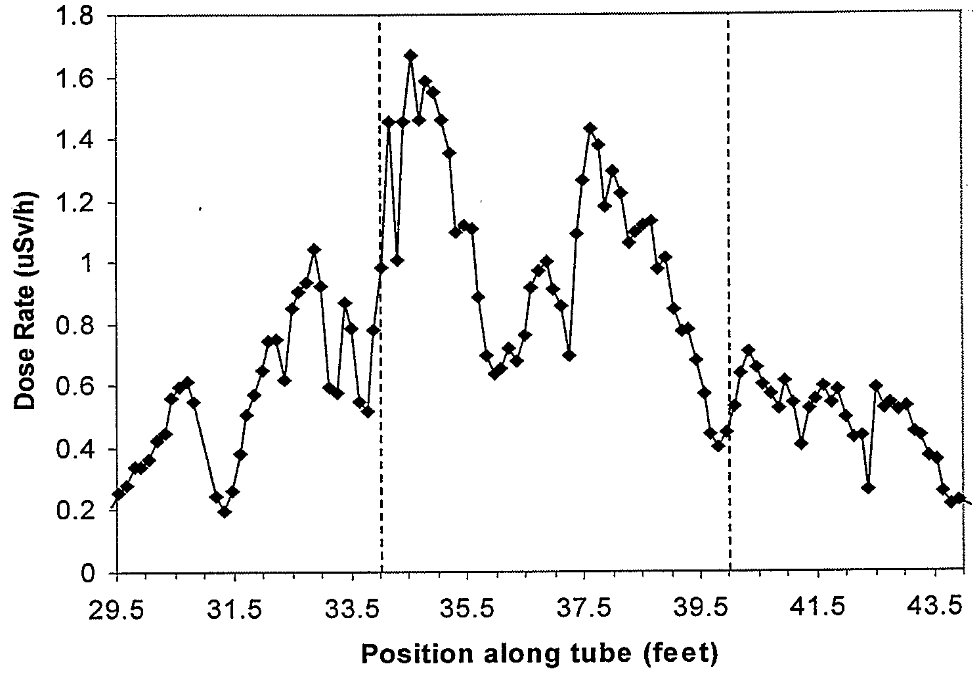

Figure 21: Dose rate versus source position, with the tube fifteen feet from the front of the vehicle.

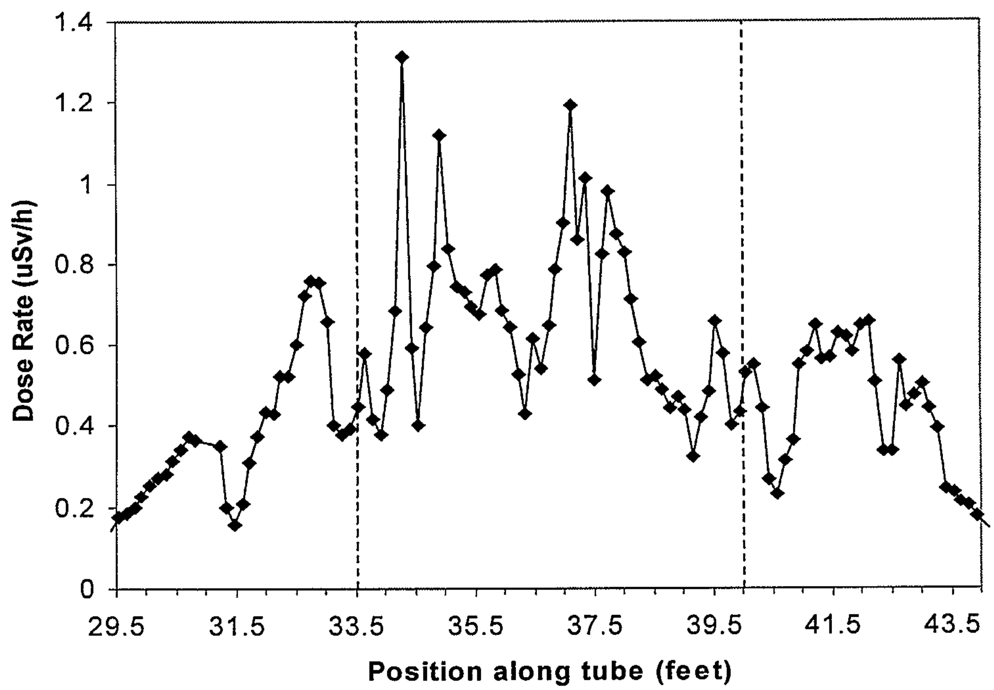

Figure 22: Dose rate versus source position with the tube sixteen feet from the front of the vehicle.

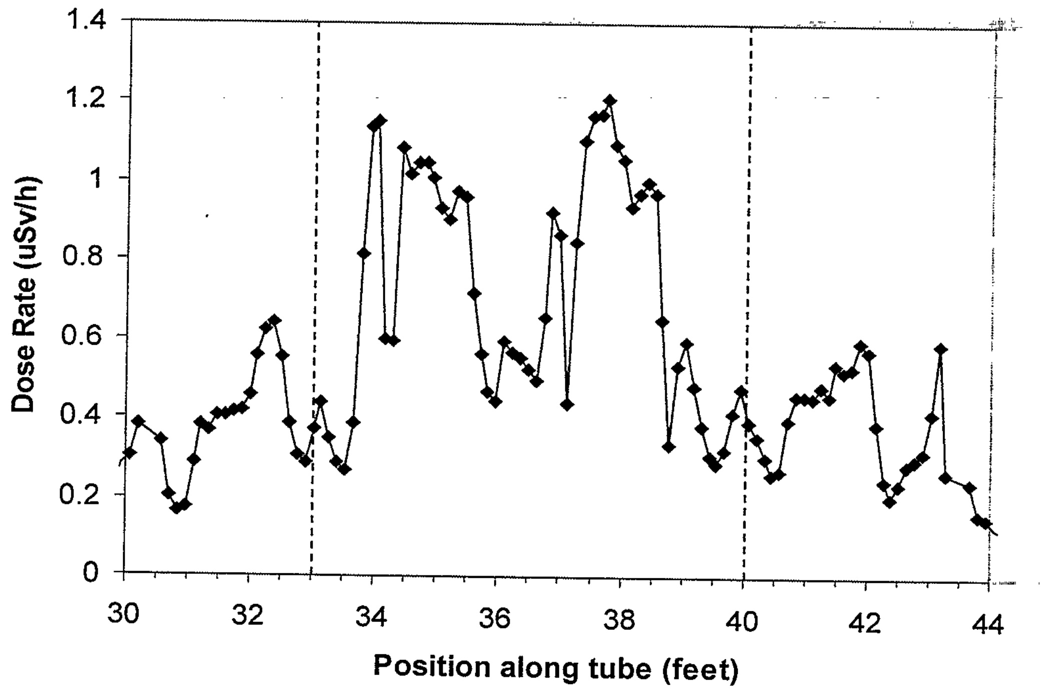

Figure 23: Dose rate versus source position with the tube seventeen feet from the front of the Grizzly.

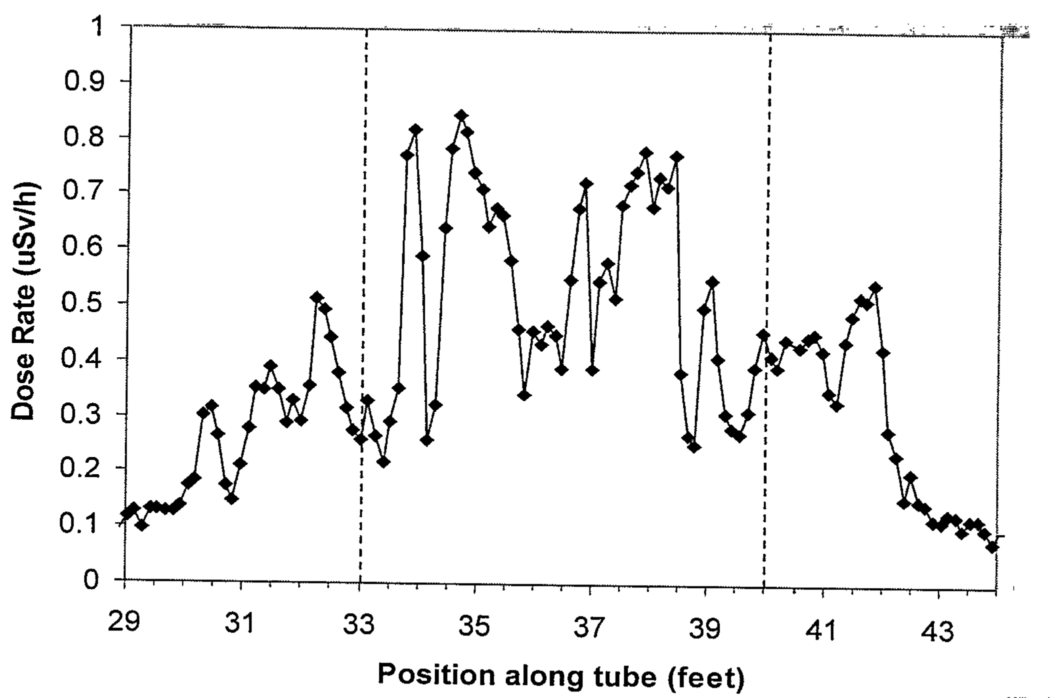

Figure 24: Dose rate versus source position with the tube at the rear end of the Grizzly.

As described earlier, both the Microspec and BGO detectors can be used to measure the total dose at the detector position for a complete trip of the source over the vehicle. For the Microspec, this amounts to taking the integral of each of the graphs in Figures 6-24; for the BGO, this is the only data that is available. Figure 25 shows these data, properly normalised, as a function of tube position, measured in feet from the front of the Grizzly. It is clear from these plots where the detectors were positioned, and how quickly the contribution to the total dose rate from contaminated surfaces falls off with distance from the detector. This is due to the inevitable inverse-square law and to the presence of more shielding materials between the source and the detector. This emphasises the importance of decontaminating vehicle surfaces that are the closest to personnel inside the vehicle.

As described in Section 2.3, when one sums the doses in Figure 25, one gets the dose that one would expect to measure in one second from a uniform vehicular contamination of $A/(dw)$ mCi/cm^2. For the Microspec, this leads to a dose rate of 39.4 rad/h/(mCi/cm^2), while the BGO result is 59.1 rad/h/(mCi/cm^2). And, given that the dose rate due to an infinite plane of contamination is 470 rad/h/(mCi/cm^2), this leads to a protection factor of 11.9 for the driver's seat, and 8.0 for the passenger's bench.

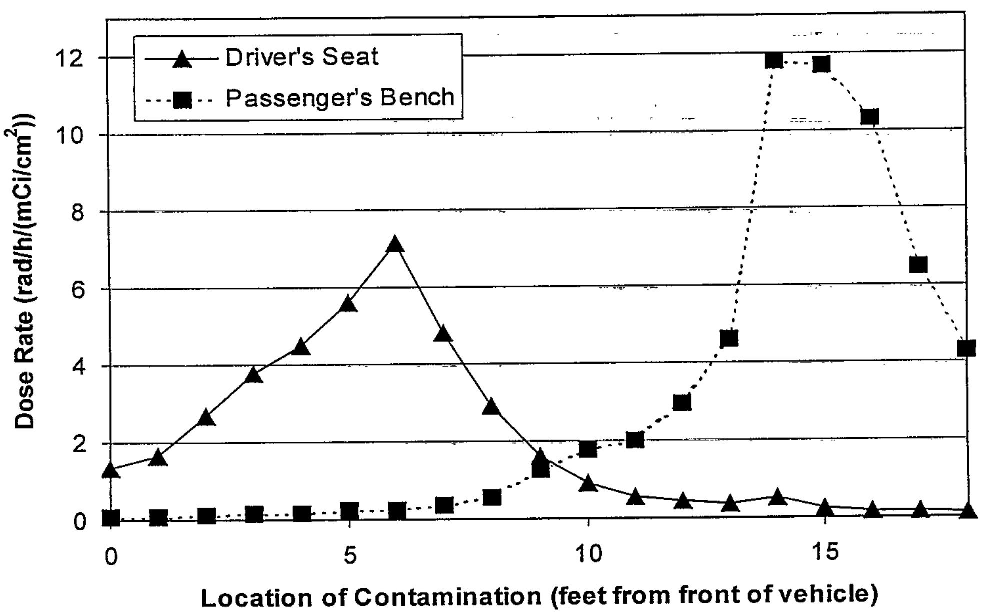

Figure 25: Dose rate as a function of the position of the contamination. Data are shown for the NaI(Tl) detector (in the driver's seat) and for the BGO detector (on the passenger's bench). The contamination is normalised to 1 mCi/cm^2.

4.0 CONCLUSIONS AND RECOMMENDATIONS

In this report, results are presented on the first measurement of gamma-ray radiation protection factors for a contaminated vehicle, specifically for the CF Grizzly Armoured Personnel Carrier. The protection factor was measured for two positions, the driver's seat and the passenger bench on the left side. In the former position, the protection factor was measured to be 11.9; in the latter position, it was measured to be 8.0.

In addition to demonstrating the ability to measure these protection factors, this report has shown that variations in the protection offered by the vehicle can be identified when the gamma-ray detector can provide time-indexed data, like the DREO Airborne spectrometer.

It is recommended that:

(i) PMO LAV consider adding procedures regarding vehicular contamination to the vehicle software packages. In that case, it would also be best to repeat these measurements with a detector in the same position as the vehicle's own detector.

(ii) DLM supply a vehicle for the decontamination trials at Bourges in September 1999. If the vehicle provided for these trials is not a Grizzly, then it would be preferable that this vehicle also be supplied to DREO for measurements in the spring or summer of 1999.

(iii) NATO define a "Contamination Protection Factor" and include it in Allied Engineering Publication AEP-14 [7]. This publication should also be updated to include all of the currently operating simulators for contaminated vehicles. This revision could be initiated through the Technical Sub-Group, soon to be renamed as the Nuclear Protection Sub-Group.

5.0 REFERENCES

[1] "Managing the Nuclear Spectrum: The Concept of Nuclear Defence for the Canadian Forces 2000-2015", 3136-6-G2199(DNBCD 2-3), 15 July 1998.

[2] T. Cousins, T. A. Jones, B. E. Hoffarth, and J. R. Brisson, "Evaluation of thhe Gamma-Ray Protection Factor of the New CF LAV", Final Tasking Report to PMO LAV: Project L265, FE #847696FGFA5, October 1996.

[3] Ph. Bouteilloux, "French Tests at Bourges", Proceedings of the Physical Dosimetry Subgroup Meeting, ATC-8009, July 1995.

[4] G. Tumbragel, "German Facilities", Proceedings of the Physical Dosimetry Subgroup Meeting, ATC-8009, July 1995.

[5] T. Cousins, B. E. Hoffarth, and K. Jaansalu, "Measurements of the Radiation Fields Around the Radiography Facility of the SLOWPOKE II Reactor at Royal Military College, Kingston (U)", DREO Report No. 1123, January 1992.

[6] "Development of Airborne Miniature Radiation Spectroscopy System with GPS", Bubble Technology Industries, Inc., Contract #W7714-6-0048/001/SV, November 1997.

[7] NATO Allied Engineering Publication (AEP-14), "Guidelines for the Armoured Vehicle Designer to Improve Nuclear Radiation Protection" Edition 3, 1993 (NATO Restricted).

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)
   Defence Research Establishment Ottawa
   Ottawa, Ontario
   K1A 0Z4

2. SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable)
   UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)
   Measurement of Radiation Protection Factors for Contaminated Vehicles (U)

4. AUTHORS (Last name, first name, middle initial)
   D. S. Haslip, T. Cousins, J. R. Brisson, B. E. Hoffarth, T. A. Jones, and J. Dubeau

5. DATE OF PUBLICATION (month and year of publication of document)
   March 1999

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)
   26

6b. NO. OF REFS (total cited in document)
   7

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)
   DREO Technical Memorandum

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)
   Space Systems and Technology Section
   Defence Research Establishment Ottawa
   Ottawa, Ontario, K1A 0Z4

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)
   6ee12

9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)
   DREO Technical Memorandum # 1999-070

10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)
   (X) Unlimited distribution
   ( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
   ( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
   ( ) Distribution limited to government departments and agencies; further distribution only as approved
   ( ) Distribution limited to defence departments; further distribution only as approved
   ( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)
   Unlimited Announcement

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

The gamma-ray radiation protection factor for contaminated vehicles has been defined and measured for two positions inside the CF Grizzly. The measurements were performed with a 60Co gamma-ray source at the DREO fallout field simulation facility. In the driver's seat, the protection factor was seen to be 11.9, while in a passenger's position closer to the rear of the vehicle, the protection factor was considerably smaller, at 8.0.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

gamma ray radiation
radiation protection factor
CF Grizzly
contamination
measurement

Leader en sciences et
technologie de la défense,
la Direction de la recherche
et du développement pour
la défense contribue
à maintenir et à
accroître les compétences
du Canada dans
ce domaine.

The Defence Research
and Development Branch
provides Science and
Technology leadership
in the advancement and
maintenance of Canada's
defence capabilities.

#511740

DEFENCE R&D DÉFENSE

www.crad.dnd.ca